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(21) Application No. 43154/76 (22) Filed 18 Oct. 1976
(31) Convention Application No. 48318
(32) Filed 19 Oct. 1975 in
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(19)

(72) Inventor ISAIA (YESHAYAHU) GLASSER-INBARI

(54) OPTICAL APPARATUS

(71) We, YEDA RESEARCH AND DEVELOPMENT CO. LTD., an Israel Company of P.O. Box 95, Rehovot, Israel, do hereby declare the invention, for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in the following statement:—

The present invention relates to optical devices and more particularly concerns optical imaging apparatus for producing an image on an image plane and a camera utilizing such apparatus.

In the design of compact optical instruments such as cameras a primary goal is the minimization of the required distance between an objective lens and an image focal plane while maximizing the size of the image produced thereon. Various types of single lenses and lens combinations have been designed in an attempt to achieve this goal but these suffer from the drawback of relatively high cost and the introduction of significant distortion in the produced image. One example of a prior art lens combination is disclosed in United States Patent 3,784,277.

Lenslet arrays are well known in the art for producing an array of small images. Such lenslet arrays have hitherto not been proposed for use in solving the above problem of maximizing image size while minimizing the required separation of the lens from the image plane due to the fact that they produce a plurality of small images rather than a single large image.

In accordance with the present invention there is provid[illegible]

lenslets such that each path transmits light representing a different portion of the image produced by each of said lenslets to said image plane, whereby the sum of the contributions of each said light path produces a completed image on said image plane.

According to an embodiment of the invention a multiplicity of lenslets each having a relatively short focal length are arranged intermediate an object and an image plane, preferably in a periodic planar array. Each individual lenslet produces a small image. Each light transmission path of the said sampling means transmits to the image plane a different portion of a corresponding small image. The sampling means preferably comprises a mask having thereon a pinhole array of periodicity slightly different from that of the lenslet array. Combination of the contributions of the individual pinholes produces a large image on the image plane.

According to alternative embodiments of the invention the lenslet array may be non-planar and random instead of periodic. In such cases the disposition and operation of the sampling means are designed to produce a combined image on the image plane similar to that produced in accordance with a preferred embodiment of the invention described above.

Further in accordance with an embodiment of the invention there is provided a "thin" camera comprising a lenslet array and sampling means as described above, light responsive photographic film disposed in the image plane and a shutter disposed intermediate the [illegible]

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The present invention relates to optical devices and more particularly concerns optical imaging apparatus for producing an image on an image plane and a camera utilizing such apparatus.

In the design of compact optical instruments such as cameras a primary goal is the minimization of the required distance between an objective lens and an image focal plane while maximizing the size of the image produced thereon. Various types of single lenses and lens combinations have been designed in an attempt to achieve this goal but these suffer from the drawback of relatively high cost and the introduction of significant distortion in the produced image. One example of a prior art lens combination is disclosed in United States Patent 3,784,277.

Lenslet arrays are well known in the art for producing an array of small images. Such lenslet arrays have hitherto not been proposed for use in solving the above problem of maximizing image size while minimizing the required separation of the lens from the image plane due to the fact that they produce a plurality of small images rather than a single large image.

In accordance with the present invention there is provided: optical apparatus for producing a relatively large image with a relatively small distance between the apparatus and an image plane comprising:

a surface distribution of lenslets in a known arrangement disposed intermediate an object and an image plane surface; and

sampling means disposed intermediate said plurality of lenslets and said image plane and defining a plurality of discrete light transmission paths, said paths being arranged with respect to the disposition of said plurality of lenslets such that each path transmits light representing a different portion of the image produced by each of said lenslets to said image plane, whereby the sum of the contributions of each said light path produces a completed image on said image plane.

According to an embodiment of the invention a multiplicity of lenslets each having a relatively short focal length are arranged intermediate an object and an image plane, preferably in a periodic planar array. Each individual lenslet produces a small image. Each light transmission path of the said sampling means transmits to the image plane a different portion of a corresponding small image. The sampling means preferably comprises a mask having thereon a pinhole array of periodicity slightly different from that of the lenslet array. Combination of the contributions of the individual pinholes produces a large image on the image plane.

According to alternative embodiments of the invention the lenslet array may be non-planar and random instead of periodic. In such cases the disposition and operation of the sampling means are designed to produce a combined image on the image plane similar to that produced in accordance with a preferred embodiment of the invention described above.

Further in accordance with an embodiment of the invention there is provided a "thin" camera comprising a lenslet array and sampling means as described above, light responsive photographic film disposed in the image plane and a shutter disposed intermediate the sampling means and the image plane.

A controlled amount of distortion may be introduced by the mechanism of the camera by altering the periodicity of lenslets forming the lenslet array or of pinholes in the pinhole array sampling means. The introduction of such small distortion may be useful in document reproducing cameras where it is necessary to overcome distortions introduced by the reproducing apparatus or in the original being photographed.

In accordance with a further embodiment

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of the invention there is provided a scanning camera in which a single dimension lenslet array and a single dimension pinhole array are disposed in parallel spaced relationship and move transversely to their axis at slightly differing velocities thereby producing a combined image on the film.

In accordance with a variation of the scanning camera described above the one dimensional lenslet array and pinhole array may be maintained fixed while both the film and the object move. The image thus produced indicates the change in object position with time.

The invention will be more fully understood and appreciated from the following detailed description taken in conjunction with the drawings in which:

Fig. 1 is a perspective view of the optical apparatus of an embodiment of the invention disposed between an object and an image plane;

Fig. 2 is a pictorial view of a camera employing the apparatus of Fig. 1;

Fig. 3 is a pictorial view of a scanning camera constructed and operated in accordance with an embodiment of the invention.

Referring now to Fig. 1 there is shown a lenslet array 10 disposed in the XY plane facing an object 11 and containing a multiplicity of lenslets having a periodicity of P_1 in the X direction and a periodicity of P_2 in the Y direction. Preferably P_1 and P_2 are selected to be identical and to be approximately 0.2 mm such that the separation between adjacent lenslets is just below the resolution limit of the human eye. For this reason, P_1 and P_2 advantageously do not exceed 0.2 mm. When identical, P_1 and P_2 are hereafter referred to as P_a.

It is to be understood that the lenslet array illustrated in Fig. 1 is merely exemplary of a wide variety of lenslet arrays which may be usefully employed in accordance with embodiments of the invention. For example, planar lenslet arrays having periodicities P_1 and P_2 along respective perpendicular X and Y axes which differ from each other may be employed or a known random periodic distribution of lenslets may alternatively be used. The lenslet array need not necessarily be arranged in a plane but may instead be disposed over any known surface. Furthermore the size and periodicity of the lenslets may be varied to suit differing applications.

Lenslet array 10 is typically formed of plastic, molded to define a multiplicity of convex lenslet surfaces. The precise configuration of the individual lenslet may be varied to suit design and manufacturing criteria. Any array arrangement such as rectangular, hexagonal or triangular may be used.

A mask 12 bearing a pinhole array is disposed generally parallel to lenslet array 10 and in light receiving relationship therebehind. The separation between lenslet array 10 and mask 12, indicated as S_1, is related to the focal length f of each individual lenslet by the following equation:

$$S_1 = \frac{f \cdot S}{S - f}$$

where S is the distance separating object 11 from lenslet array 10. Normally, as S is much larger than f, f may be taken as a good approximation to S_1. Thus where f, the focal length of each lenslet is selected to be 1 cm., S_1 is selected to be also 1 cm.

Pinholes 14 are distributed on mask 12 with a periodicity P_3 along Y axis and a periodicity P_4 along the X axis which are preferably identical and which differ slightly from the periodicity of the lenslets in array 10. When identical, P_3 and P_4 will hereinafter be referred to as P_b. Where $P_a = 0.2$ mm, P_b conveniently may be selected to be 0.22 mm.

According to a more general embodiment of the invention described above wherein the planar lenslet array may have differing periodicities along the X and Y axes, or may contain a random known distribution of lenslets, the positional relationship between the centre of each individual lenslet in array 10 and a corresponding pinhole in mask 12 is given by the following equations:

$$X_i' = X_i(1 + e_x)$$

$$Y_i' = Y_i(1 + e_y)$$

where

- X_i' is the position of the i'th pinhole of the X axis,
- Y_i' is the position of the i'th pinhole along the Y axis,
- X_i is the position coordinate of the center of the i'th lenslet along the X axis,
- Y_i is the position coordinate of the center of the i'th lenslet along the Y axis, and
- e_x and e_y are constants or smooth functions which vary no more than 25% from a constant value.

The absolute values of e_x and e_y are selected to be small fractions. Each lenslet in array 10 forms an individual small image 16 in the plane defined by mask 12. One point of each image is picked up by a pinhole and transmitted. The rest of the light forming the image is blocked. Since the period P_b of the pinhole array on mask 12 is slightly different from period P_a of the lenslet array 10 each pinhole transmits a different point of each small image. The entire set of transmitted points combines to form a relatively large image 18 on an image plane 20.

The lenslet array-pinhole mask combination may be appreciated to have an effective focal length given by the following expression:

$$F = \frac{f \cdot P_a}{P_b - P_a}$$

where P_a is the periodicity of the lenslet array and P_b is the periodicity of the pinhole array.

According to an alternative embodiment of the invention, mask 12 need not comprise a pinhole array but may instead be any type of device which provides an array of discrete light transmission paths.

According to a further alternative embodiment of the invention other types of radiation aside from visible light may be imaged using the apparatus described herein.

Referring now to Fig. 2 there is shown a camera employing a lenslet array 30 arranged to receive light from an object. A pinhole mask 32 is disposed generally parallel to array 30 and spaced therefrom by a distance S_1. Photographic film 34 of any suitable type and arrangement is disposed at the image plane behind mask 32. A shutter mechanism 36 is operative to allow selected access of light to film 34 and comprises a driving unit 38 and a pinhole mask 40 disposed intermediate mask 32 and film 34. Mask 40 may be conveniently constructed to have a distribution of pinholes having periodicity identical to that of the pinholes on mask 32. Film 34 is separated from mask 40 by a distance S_2 sufficient to allow diffusion of the light transmitted through the pinholes so as to form a smooth image. S_2 may be conveniently selected to be approximately equal to S_1. When shutter 36 is in a closed position mask 40 is disposed slightly out of phase with mask 32 so that light passing through mask 32 is not transmitted to mask 40. Opening of shutter 36 is accomplished by a slight movement of mask 40, bringing the pinholes of mask 40 into alignment with those of mask 32, and thereby permitting the passage of light to film 34.

According to an alternative embodiment of the invention, controlled distortion correction for accurate reproduction cameras may be accomplished by introducing slight distortions into the periodicity of the lenslets forming array 30, particularly along the peripheral edges of the lenslet array. The precise amount of distortion introduced is designed to compensate for other known spurious distortions introduced by the remainder of the optical system or present in an original being photographed. Similarly distortions in the periodicity of the pinholes in mask 32 may be employed for distortion correction.

Referring now to Fig. 3 there is shown a camera employing a linear array of lenslets 50 and a corresponding linear pinhole mask 52. Lenslet array 50 may conveniently have a periodicity of P_x equal to 0.2 mm. and pinhole array mask 52 may have a pinhole periodicity of P_y=0.22 mm.

Drive means 54 are provided for moving lenslet array 50 and pinhole mask 52 at independently selectable velocities with respect to photographic film 56 disposed behind mask 52. A movable curtain 58 prevents light not passing through the lenslet array from reaching film 56. Film 56 remains static during exposure and the lenslet array is moved transversely thereto at a velocity V_1 while the pinhole array is moved at a velocity V_2. The ratio of velocities V_1 and V_2 is selected to be substantially equal to the ratio of P_x and P_y thus providing an image on the film equivalent to that produced by the camera of Fig. 2.

According to an alternative embodiment of the invention pinhole array mask 52 and lenslet array 50 may be maintained fixed while film 56 and the object being viewed move. Such a camera may be useful for continuous copying or as a finish line racetrack camera, where the transverse position of an image on the film is a function of the particular moment in time when the exposure was made.

WHAT WE CLAIM IS:—

1. Optical apparatus for producing a relatively large image with a relatively small distance between the apparatus and an image plane comprising:

a surface distribution of lenslets in a known arrangement disposed on the object side of an image plane surface; and

sampling means disposed intermediate said lenslets and said image plane and defining a plurality of discrete light transmission paths, said paths being arranged with respect to the disposition of said lenslets such that each path transmits light representing a different portion of the image produced by each of said lenslets to said image plane, whereby the sum of the contributions of each said light paths produces a completed image on said image plane.

2. Optical apparatus according to Claim 1 wherein said surface distribution of lenslets comprises a planar distribution of substantially identical lenslets disposed in spaced parallel relationship to said image plane.

3. Optical apparatus according to Claims 1 or 2 wherein said sampling means comprises a generally planar mask disposed parallel to and spaced from said lenslet array by a distance S_1 and having formed thereon a pinhole array, permitting light from said lenslets to pass through said mask at discrete positions thereon.

4. Optical apparatus according to either of Claims 2 or 3 wherein said lenslets are arranged to have a first periodicity P_1 along an X axis of said planar array and a second

periodicity P_2 along a Y axis of said planar array.

5. Optical apparatus according to Claim 5 wherein P_1 and P_2 do not exceed 0.2 mm.

6. Optical apparatus according to either of Claims 4 or 5 wherein said first periodicity P_1 is identical to said second periodicity P_2.

7. Optical apparatus according to Claim 3 and either of Claims 4 or 5 wherein said pinhole array is arranged on said mask to have a periodicity P_4 along said X axis and a periodicity P_3 along said Y axis and wherein said periodicities P_4 and P_3 differ slightly from respective periodicities P_1 and P_2.

8. Optical apparatus according to any one of Claims 2 to 7 wherein the positional relationship between each individual lenslet and a corresponding pinhole is given by the following equations

$$X_i' = X_i(1+e_x)$$

$$Y_i' = Y_i(1+e_y)$$

where

X_i' is the position of the i'th pinhole of the X axis,

Y_i' is the position of the i'th pinhole along the Y axis,

X_i is the position coordinate of the center of the i'th lenslet along the X axis,

Y_i is the position coordinate of the center of the i'th lenslet along the Y axis, and

e_x and e_y are constants or smooth functions which vary no more than 25% from a constant value.

9. Optical apparatus according to Claim 6 wherein where the focal length of each lenslet is given by f, the effective focal length F of the apparatus is given by

$$F = \frac{f \cdot P_a}{P_b - P_a}$$

where P_a is the periodicity of the lenslet distribution and P_b is the periodicity of the pinhole array.

10. Optical apparatus according to any of the previous claims and additionally comprising shutter means disposed intermediate said sampling means and said image plane.

11. Optical apparatus according to any of the previous claims wherein said shutter means comprises a pinhole array identical in arrangement to the disposition of said discrete light transmission paths, said shutter means being disposed in a normally closed position wherein said pinhole array is not aligned with said light transmission paths and being movable into an open position wherein said light transmission paths and said pinhole array are in alignment.

12. Optical apparatus according to Claim 1 wherein said surface distribution of lenslets comprises a single row of lenslets disposed in a plane and wherein said sampling means comprises a mask these being formed therein a single row of pinholes, the lenslets being arranged with a first periodicity and said pinholes being arranged to have a second periodicity slightly different from said first periodicity;

said optical apparatus additionally comprising photographically sensitive material;

a movable screen blocking the passage of light to said photosensitive material through said lenslets; and

means for moving said row of lenslets across said photosensitive material in a direction transverse to the axis of said lenslet row at a first velocity; and

means for moving said row of pinholes across said photosensitive material in a transverse direction to the axis of said row of pinholes at a second velocity, slightly different from said first velocity and related to said first velocity by a ratio substantially identical to the ratio between said second periodicity and said first periodicity, whereby relative movement of said row of lenslets and row of pinholes with respect to said photosensitive material produced a scanned image thereon.

13. Optical apparatus according to Claim 1, substantially as shown and described hereinabove.

14. Optical apparatus substantially as shown in Fig. 1.

15. Optical apparatus substantially as shown in Fig. 2.

16. Optical apparatus substantially as shown in Fig. 3.

17. Optical apparatus according to any one of Claims 1 to 16 and wherein each lenslet has a focal length f, when positioned with respect to an object of which an image is to be formed such that

$$S_1 = \frac{f \cdot S}{S - f}$$

where S_1 is the distance between the lenslet distribution and the mask and S is the distance between the lenslet distribution and the object.

18. A method of taking a photograph

characterised by the use of an apparatus according to any one of Claims 1 to 17.

19. A photograph when produced by the method of Claim 18.

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1507809 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

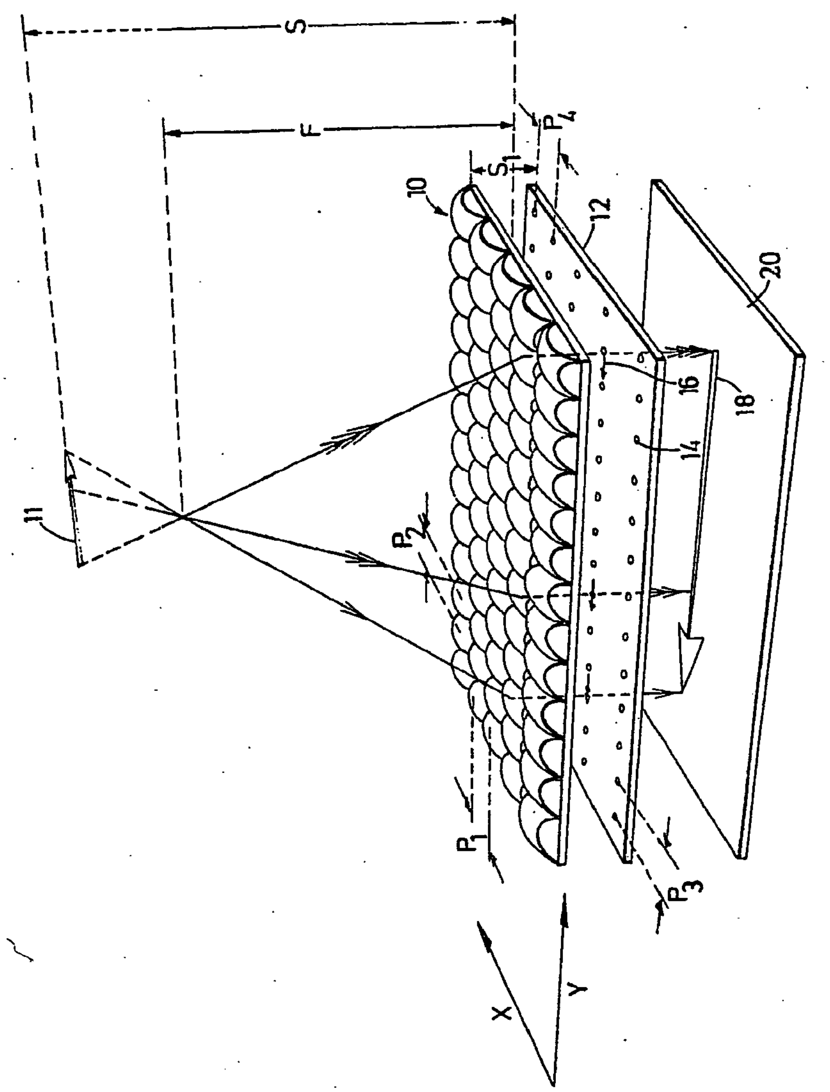

Fig. 1

1507809 COMPLETE SPECIFICATION

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Sheet 2

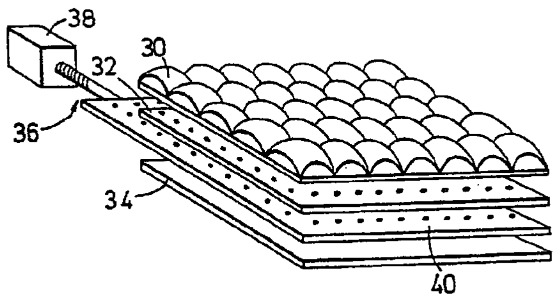

Fig. 2

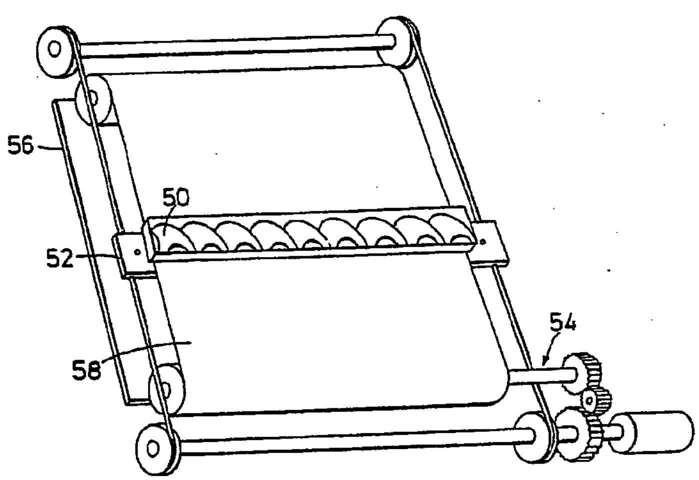

Fig. 3